STORMWATER ACTION MONITORING (SAM) ROUND 4
EFFECTIVENESS STUDY AND SOURCE IDENTIFICATION
PROJECT PROPOSAL

May 31, 2023

Letter of Intent #3:
Measuring Street Sweeping 6PPD-q Whole Environment Load Reductions

Seattle Public Utilities

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1 SUBMITTAL INFORMATION

Letter of Intent: LOI #3
Title: *Measuring Street Sweeping 6PPD-q Whole Environment Load Reductions*
Priority Topic: 9. Stormwater management of 6PPD-quinone - Study street sweeping to get more information about 6PPD/q removal

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2 INTRODUCTION

Identifying 6PPD-q as Urban Runoff Mortality Syndrome's cause has re-focused awareness on roadways as prolific producers of potent stormwater pollutants. This study will examine the potential for street sweeping to reduce the source of 6PPD-q on the roadway. Figure 1 illustrates our working hypothesis, which theorizes that regularly scheduled street sweeping will remove tire and road wear particles (TRWP) generated by the friction of tires on the road pavement. A whole environment (water/sediment, air, and land) focus considers reductions in the amount of 6PPD-q available to wash or blow off roadways and ultimately enter nearby surface waters via wet and/or dry deposition.

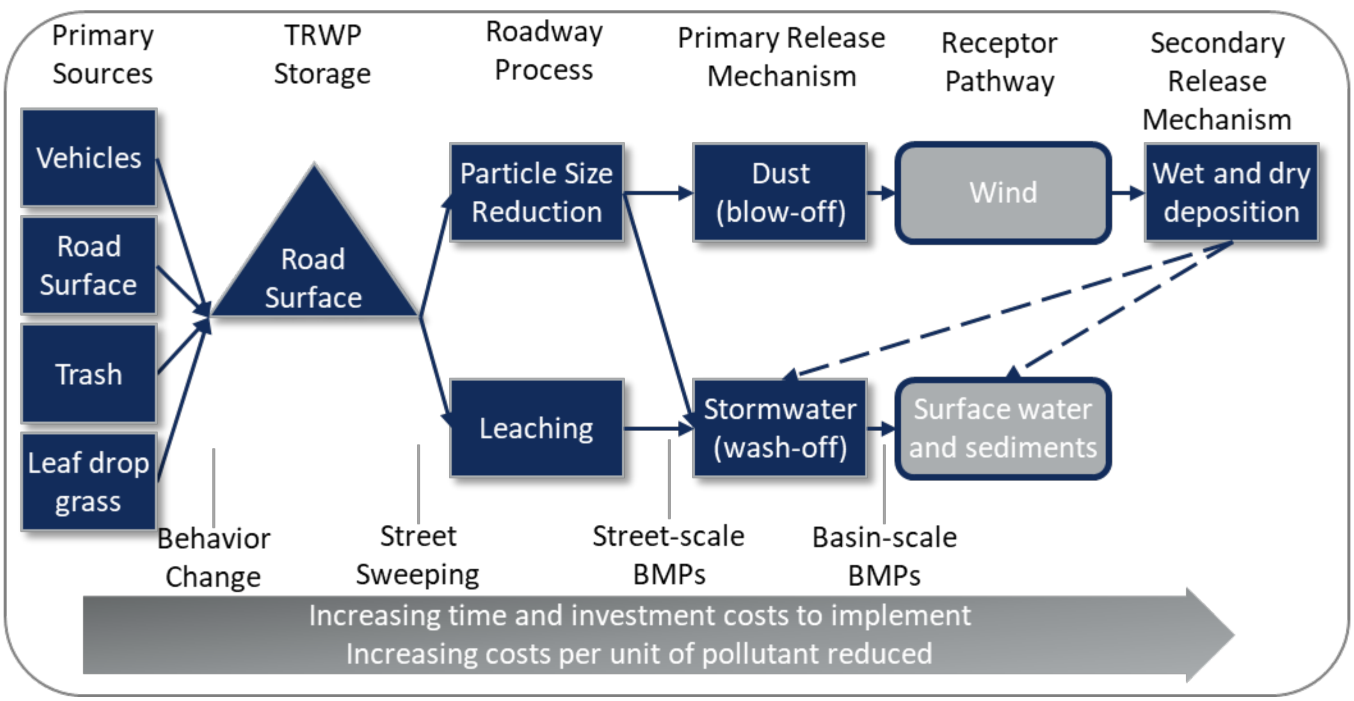

Figure 1. Tire and Road Wear Particle (TRWP) pathway receptor network diagram highlights source control.

Figure 1 also indicates the increasing time and investment needed to address roadway pollutants using treatment Best Management Practices (BMPs). This highlights the potential for street sweeping, a source control BMP, as an early action to address 6PPD-q and focuses the study design.

Key questions. This proposal will address the following key questions around street sweeping arterials in the City of Seattle using regenerative air sweepers:

- Does street sweeping reduce 6PPD-q loads from Seattle's arterials?
- Are 6PPD-q and other parameter (Table 1) concentrations and pickup rates influenced by particle size, season, or land use?
- Can we detect a correlation between 6PPD-q and zinc, another tire contaminant? If so, could zinc be used as a 6PPD-q indicator to reduce analytical costs?
- What other contaminants does street sweeping reduce?

3 APPROACH RATIONAL

The proposed approach, direct measurement and characterization of the swept material, builds on the City of Seattle (City) street sweeping program's ongoing monitoring and evaluation efforts. From 2013 through 2018 the City collected and analyzed samples approximately every other week from two locations to assess performance. In 2019, the sampling frequency was reduced to quarterly. The results generally show higher concentrations in the <250 um fraction compared to the >250 um fraction and significant temporal (season and year over year) and spatial (land use) concentration and pickup variations (SPU 2023).

More importantly, the results highlight street sweeping's source control benefits. SPU (2023) estimates street sweeping wash-off load reductions represent around 10%, 13%, 16%, 23%, and 22% of the TSS, phosphorus, zinc, copper, and lead whole environment load reductions, respectively. This means approximately 87%, 84%, 77%, and 78%, of the phosphorus, zinc, copper, and lead, respectively removed by sweeping may provide additional source control benefits. Impervious area in the City ranges from an average of 65% within 100 feet of swept arterials to 58% within 500 feet. Street sweeping likely substantially reduces the pollutants blown off the road and deposited on these impervious surfaces and consequently washed to the stormwater system.

A review of the literature demonstrates uncertainty around sweeping effectiveness and lack of a standardized evaluation method (Hixon and Dymond 2018). An expert panel convened by the Chesapeake Bay Program Partnership to review literature around street sweeping effectiveness concluded a paired basin stormwater monitoring approach was impractical due to the required sample size and recommended a modeling approach to optimize and predict street sweeping pollutant load reductions (CBPP 2016). However, a general shift in approach, from paired basin stormwater monitoring to characterization of swept material to plan and assess basin goals, particularly for nutrients, has resulted in increasing acceptance of street sweeping as an effective source control BMP (Hixon and Dymond 2019, Minnesota 2023).

The key advantages of the direct measurement and swept material characterization approach compared to the paired basin stormwater monitoring approach are summarized below:

- **Better represents source control benefits:** Direct measurement accounts for reductions in whole environment wash-off + blow-off loads, compared to stormwater monitoring, which captures reductions in wash-off concentrations only.

- **Smaller sample size required:** Direct measurement sample concentrations exhibit less variability, with coefficients of variation (COVs) less than 0.5, except fecal coliform, (SPU 2023) compared to stormwater with COVs typically >1.25 (Pitt 2011).
- **Better sensitivity to obtain measurable results:** Direct measurement achieves measurable results for metals, nutrients, bacteria, hydrocarbons, PCBs, and 6PPD-q with less success for semi-volatile compounds (SPU 2023) compared to stormwater monitoring, which is challenged to consistently achieve measurable results (Hixon and Dymond 2019).
- **Fit to purpose spatial and temporal boundaries**: Direct measurement geographic scope and schedule boundaries can be adjusted to meet program needs compared to stormwater monitoring, which is usually limited in spatial scale (several blocks) and time (a snapshot over one to two years) due to logistical and cost considerations.
- **More relevant outcomes:** Direct measurement produces pickup rates for use in basin planning and measured wash-off and blow-off load reductions to assess progress towards meeting basin goals to protect and/or improve receiving water quality and habitat. Stormwater monitoring produces concentration reductions as input to a model, to predict load reductions.
- **More useful efficiency/effectiveness metric:** Direct measurement produces pickup rates, which indicate how effective sweeping is under varying conditions and provides a metric for planning and performance. Stormwater monitoring produces percent removal efficiency, which although potentially useful for comparing the ability of street sweeping to reduce wash-off concentrations against treatment BMPs, provides minimal use in planning or monitoring a street sweeping program.
- **More practical to implement**: Direct measurement is straight forward to implement when measuring a street sweeping program's performance, simply requiring collecting composite grab samples at temporary stockpiles, compared to stormwater monitoring, which provides several challenges: finding at least two comparable basins (land use, traffic flow, traffic density, traffic speed, wind, street type, and street slope, etc.), chasing storms, costs, and logistics (traffic control, permitting, monitoring installations, etc.).

4 STUDY DESIGN AND METHODS

The proposed approach includes direct measurement and characterization of "sweepings", the roadway-deposited sediment consisting of trash, leaves, debris and attached pollutants picked up by the street sweeper, coupled with a Particulate Matter Wash-off (PMWO) model to estimate the wash-off component. An expert panel reviewed and approved this performance-based monitoring approach during Seattle's Consent Decree negotiations with both the Environmental Protection Agency and the Washington Department of Ecology (SPU 2015a, SPU 2015b).

Figure 2 presents the City's monitoring and evaluation results framework which forms the basis for ongoing monitoring and evaluation to assess the joint SPU and Seattle Department of Transportation (SDOT) sweeping partnership. The proposal would cover the cost of analyzing roadway debris to turn results into outcomes.

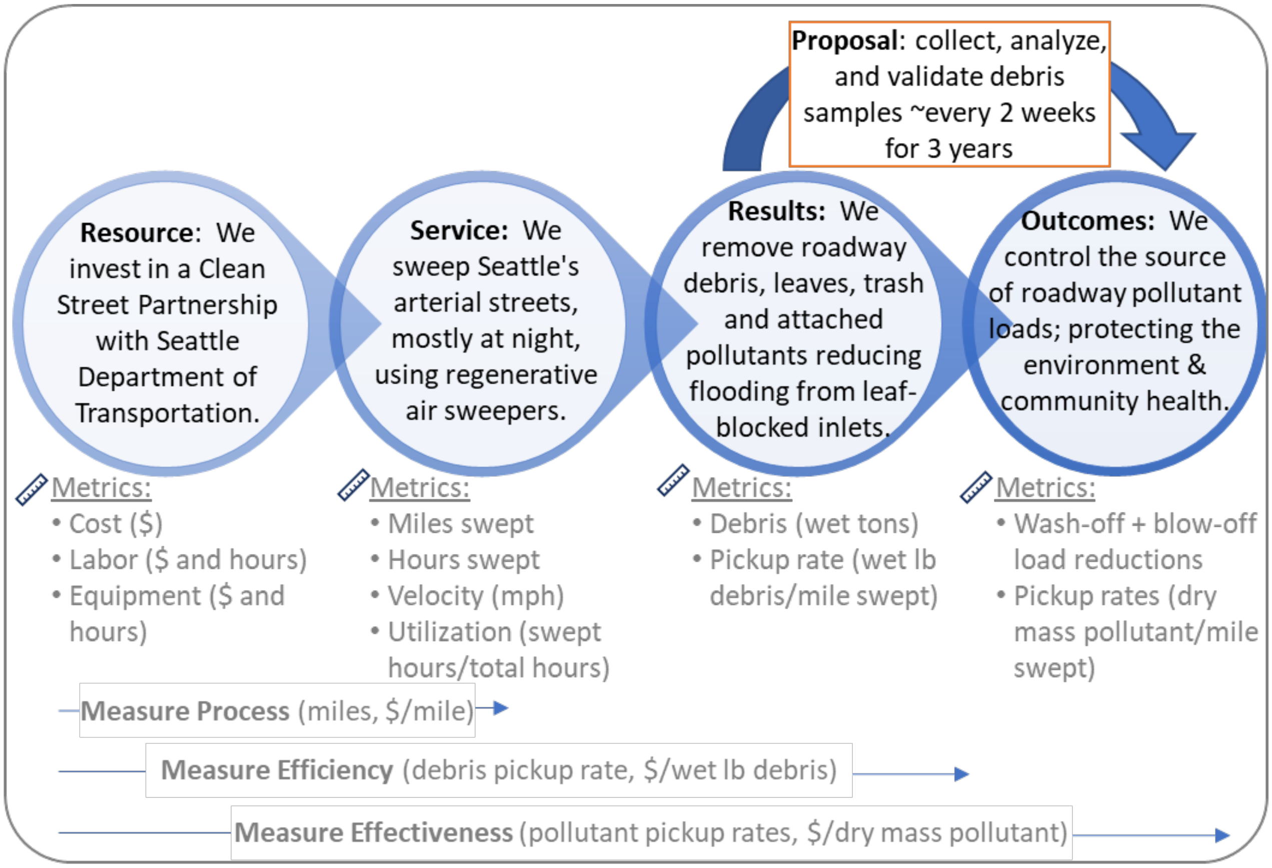

Figure 2. Monitoring and evaluation results framework.

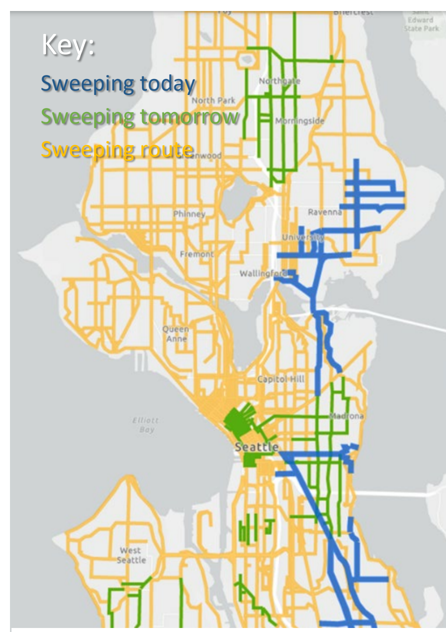

Figure 3. Route map showing route schedule by color.

Study Area. Figure 3 shows the current street sweeping program route map. Routes cover around 90% of the City's arterials. Northern routes cover more residential, 65% compared to 40% for southern routes, less commercial, 32% compared to 41% for southern routes, and less industrial, 3% compared to 19% for southern routes.

Operational Scope. Sweeping occurs mostly at night using regenerative air street sweepers. Each sweeper is equipped with Automatic Vehicle Location (AVL) and onboard scales.

Operators typically empty their hopper two to three times each shift at temporary stockpiles located in a north or south designated bin. The City empties bins periodically, weekly to biweekly, and hauls the sweepings to a private vendor for landfill disposal.

The AVL system reports time and distance sweeping and travelling. The sweeping time and distance are broken down by sweeping the specified route, sweeping the portion of the specified route that drains to the municipal separate storm sewer system (MS4), and sweeping a non-specified route. The vendor's truck scales measure the wet load removed.

Sample Collection and Analysis. Composite samples will be taken at approximately two to three feet below the surface of two temporary stockpiles, one located in the north representing the routes north of the Ship Canal, and one in the south, representing routes south of the ship canal.

A commercial laboratory will receive a field split that includes the Primary Environmental Sample (PES), representing the whole environment concentrations, and the LT250 sample, that will represent the direct wash-off to waterways concentrations after sieving to less than 250 um. The commercial laboratory will analyze the fractions for a range of parameters (Table 1).

Table 1. Analytical parameters.

Parameters
Primary Environmental Sample (PES): Grain size, Total Organic Carbon, Fecal coliform bacteria, Total Kjeldahl Nitrogen, pH, Total Solids, TPH NW, 6PPD-Q ($1,970)
PES + <250 um Fraction: Metals (Ag, As, Cd, Cr, Cu, Hg, Ni, Pb, Zn), PCBs, Total Phosphorus, 6PPD-Q ($1,250)

Sample size estimate. A three-year study period will result in approximately 24, 30, and 18 samples per location for the wet (Jan through Apr), dry (May through Sep), and leaf (Oct through Dec) seasons, respectively. Seasonal comparison may provide insights into sweeping effectiveness for western compared to eastern Washington.

Data reduction. Estimating the wash-off and blow-off load components requires six steps:

- **Step One:** Estimate the dry basis whole environment load removed by applying the PES Total Solids concentrations to the wet basis debris load removed, as measured using vendor truck scales.
- **Step Two:** Estimate the total suspended solids equivalent (TSS_{eq}) concentration by applying Particulate Matter Wash-off (PMWO) factors for wet season (50, 49, 30, 19, 12, and 6 percent) and dry season (39, 28, 20, 15, 8, and 7 percent) for six size fractions (<63 µm, 63 to 125 µm, 125 to 250 µm, 250 to 500 µm, 500 to 1,000 µm, and 1,000 to 2,000 µm), respectively. Wash off is dependent on the available sediment supply, rain energy available to loosen the material, and the capacity of the runoff to transport the loosened material. Pitt (1985) measured 50 paired debris samples on Bellevue residential streets from 1978 through 1983, close to the beginnings and ends of rain events and developed these seasonal PMWO factors. He also found a debris load reduction of about 16 percent for each rain event.
- **Step Three:** Estimate the dry basis wash-off load by multiplying the TSS_{eq} concentration (Step Two) by the dry basis whole environment load (Step One).
- **Step Four:** Estimate the dry basis whole environment pollutant loads by multiplying the PES pollutant concentrations by the dry basis whole environment load (Step One).
- **Step Five:** Estimate dry basis wash-off pollutant loads by multiplying pollutant concentrations in the less than 250 µm fraction to the dry basis wash-off load (Step Three).
- **Step Six:** Estimate the dry basis blow-off pollutant loads by subtracting the wash-off pollutant load (Step five) from the whole environment pollutant load (Step one).

Figure 4 summarizes the study approach.

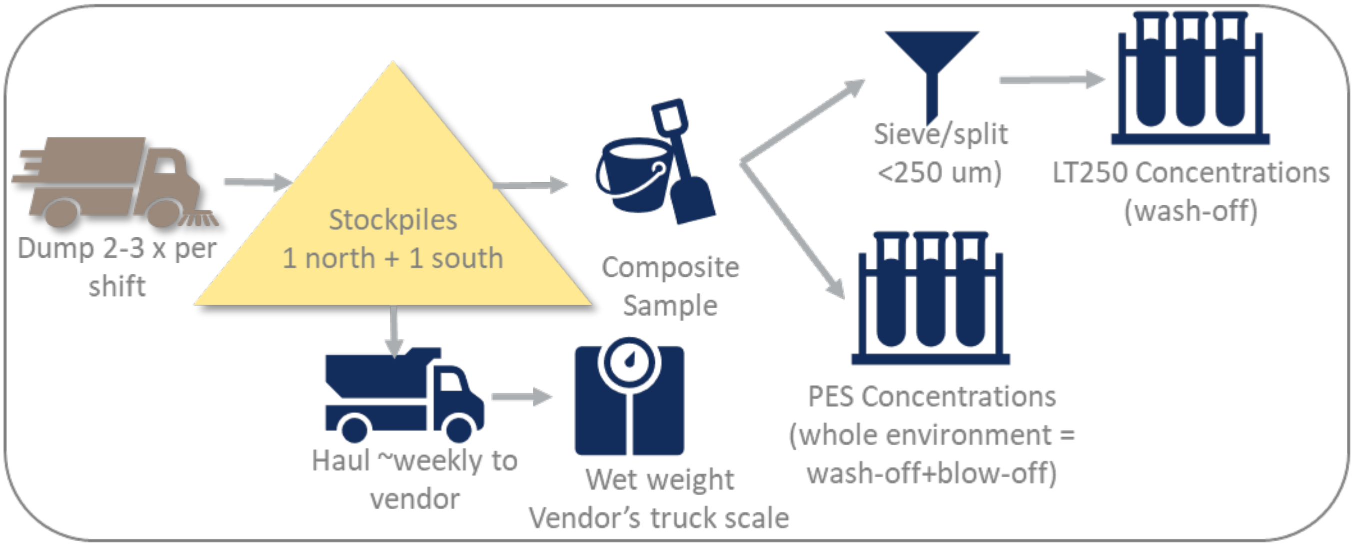

Figure 4. Data collection schematic.

5 PROJECT MANAGEMENT, TASKS, AND TEAM

A well-structured project management strategy supports better teamwork, improved project delivery, and efficiency. The existing quality assurance project plan (QAPP) will set the foundation and key project management tools and methodology will follow the PMBOK approach. The organizational structure is designed to provide project control and proper quality assurance/quality control (QA/QC) for field investigations.

Deliverables

1.1 Quality Assurance Project Plan
3.1 Samples
4.1 EDD
4.2 EDD Validated
4.3 Annual reports
5.1 Stormwater Working Group (SWG) presentation
5.2 SAM Fact Sheet
5.3 Final Report

Project Tasks. Key project tasks are listed below.

Task 1.0 Project Administration/ Management. Carry out all work necessary to deliver the work products including planning, scheduling, coordinating, data analysis, data and document management, and communications. Revise the existing QAPP.

Task 2.0 Sweep and collect operations data. Sweep under typical operating conditions (e.g., arterials swept mostly at night without parking enforcement using regenerative air sweepers) and collect and analyze sweeping operations data.

Task 3.0 Collect samples representing debris picked up by sweepers. Collect composite samples around every other week, taken at approximately two to three feet below the surface of two temporary stockpiles representing north and south Seattle over a three-year period.

Task 4.0 Analyze debris samples for selected parameters (Table 1). Receive and review each Electronic Data Deliverables (EDD) package, submit reviewed EDD to validation contractor, review and accept validated data packages. Complete an annual report summarizing the work.

5.0 Summarize, report, and communicate findings. Calculate load reductions and pickup rates (mass per broom-mile swept). Analyze the data to find trends, correlations, outliers, and variations. Interpret the analysis results, make recommendations, and clarify the limitations.

Project Team. Figure 5 provides the names, duties, and responsibilities of all key team participants, including internal and external team members as well as the lines of authority and reporting. In general, the Principal Investigator (PI), reporting to the Program Manager, is assigned to manage the monitoring study. In this role, he/she provides technical expertise; coordinates sampling activities with the laboratory, coordinates the field team; and reports the status and results of the study to the Program Manager. The Technical Advisory Committee will review the study design and key and final deliverables.

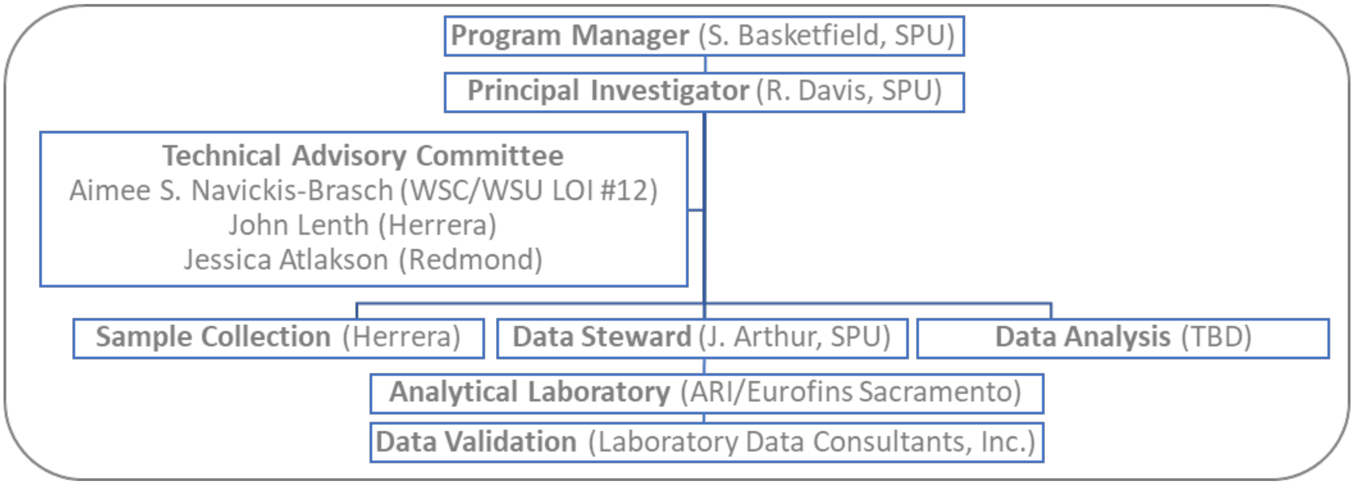

Figure 5. Project team.

Similar Project Performance. The SPU team members have implemented the proposed approach since 2013 and reported results under Seattle Integrated Plan, a component of their Consent Decree. Figure 6 presents the results from a 2022 pilot study conducted by the team to confirm the presence of 6PPD-q in street sweeping debris.

Lessons learned over the years have been incorporated into the QAPP. Recent lessons learned focused on improving holding time exceedances for 6PPD-q analysis. Samples are now collected on Monday or Tuesday, placed in a glass jar and then a zip lock bag so that the samples arrive during normal business hours, and if the ice melts, the melt water cannot enter the jar.

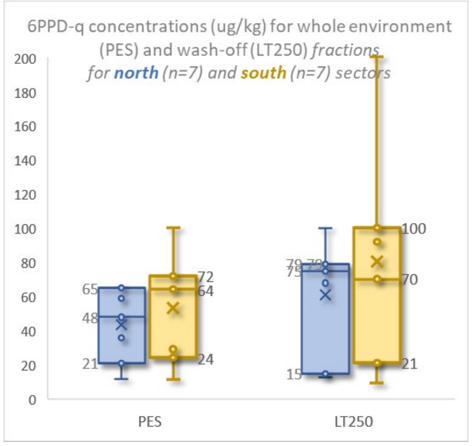

Figure 6. Preliminary 6PPD-q concentrations from Seattle's street sweeping.

6 BUDGET AND TIMELINE

The study will be conducted over a four-year period, including approach review; sample collection, analysis and validation; data analysis; and reporting. Table 2 provides an estimated 4-year budget of $765k for the study proposal outlined above. Resources to deliver tasks 1.0, 2.0, and 5.0 will be provided by SPU.

Table 2. Estimated 3-year budget.

Task	Task Deliverables	Units	Unit Cost	Proposal Costs
1.0 Project Management	1.1 Revised Quality Assurance Project Plan	1	in-kind	$0
3.0 Collect samples	3.1 Composite samples ~ 25/year	25 x 3	$1700/sample event	$127,500
4.0 Analyze debris samples	4.1 EDD ~25/year x 2 locations + QC	54 x 3	$3,220/sample	$521,640
	4.2 Validated EDDs	54 x 3	$283/sample	$45,846
	4.3 Annual Report	2	in-kind	$0
5.0 Report findings	5.1 SWG Presentation	1	in-kind	$0
	5.2 SAM Fact Sheet	1	in-kind	$0
	5.3 Final Report	1	in-kind	$0
Contingency @ 10%				69,498
TOTAL				**$ 764,484**

Figure 7 summarizes the proposed schedule, with an understanding that the grant process is unknown and will likely impact implementation. It would be preferred to start sample collection at the beginning of the calendar year for year-over-year comparisons. However, as a compromise sample collection could begin at the start of a season; wet (January), dry (May), or leaf (October).

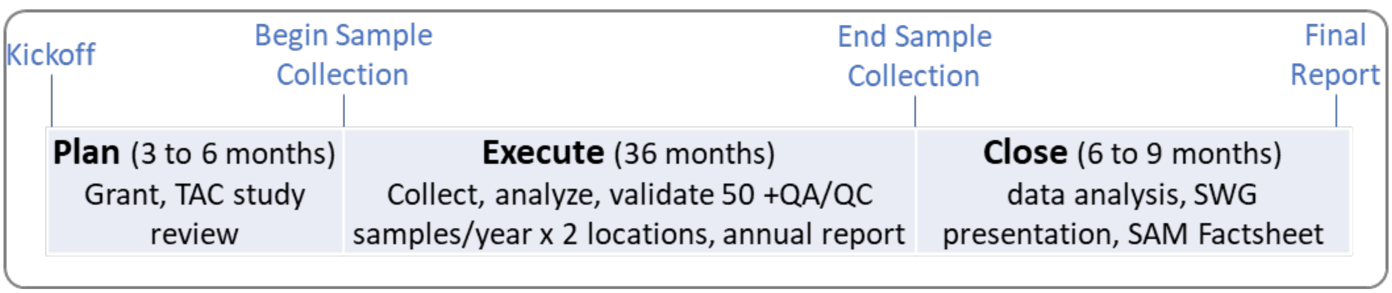

Figure 7. Project schedule showing key milestones.

7 EXPECTED OUTCOMES AND IMPLICATIONS

This study intends to provide evidence that street sweeping will reduce the amount of 6PPD-q washing and blowing off roadways, potentially providing a valuable early action to address 6PPD-q sooner rather than later, while other efforts focus on product replacement, fate and transport, and treatment BMP effectiveness.

Key Results. The study results, which will represent sweeping predominantly residential land use arterials (north Seattle) and downtown, industrial, and port land use arterials (south Seattle) with regenerative air sweepers, will include 6PPD-q and selected pollutant parameters (Table 1). The results will be provided by season, location, and whole environment wash-off/blow-off load components (where applicable) and include:

- concentrations for the whole sample and less than 250-micron particles
- pickup rates (dry mass removed/broom-mile)
- unit costs (present value $ per dry mass removed)
- load reductions (dry mass)
- ratio of dry pollutant load reduction to wet mass debris

Key Implications. This new information will help permittees and Ecology adaptively manage street sweeping programs to better address stormwater impacts in urbanizing watersheds and specifically to target 6PPD-q load reductions.

- **Seasonal differences** may influence route schedules and sweeping frequency. Dry season results may reflect conditions found in Eastern Washington urban watersheds.
- **Under-appreciated blow-off load reductions** may influence basin planning efforts and increase the use of street sweeping to optimize stormwater management cost-effectively.
- **A possible 6PPD-q indicator** may reduce future sample costs. If a correlation between 6PPD-q and another parameter is found, this parameter could serve as a 6PPD-q indicator.
- **A range of ratios representing pollutant load reductions to wet mass of debris** may be used by permittees to estimate pollutant load reductions from measured wet debris reductions.
- **Proper disposal** may be better informed with concentration data.

Limitations. The study design has several limitations, including:

- Although TRWP has been assumed to be one of the major sources of microplastic pollution and a source of 6PPD-q, analysis of TRWP will not be considered at this stage due to measuring challenges (Järlskog et al 2022).
- The study will not measure the amount of 6PPD-q available on the road. This may be considered in the future with a better understanding of fate and transport. The logistics of collecting street dirt samples from the roadway on high volume arterials is challenging.

8 CONCLUSION

We look forward to working with the SWG and supporting Ecology's efforts to improve the effectiveness and implementation of the National Pollutant Discharge Elimination System (NPDES) MS4 general permits. We believe source control, in particular street sweeping, has the potential to play a key role in cost-effectively protecting and improving the health of our receiving waters.

Thank you for your consideration,

Gary Christiansen
Source Control & Pollution Prevention Interim Division Director
Seattle Public Utilities

Seattle Public Utilities

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